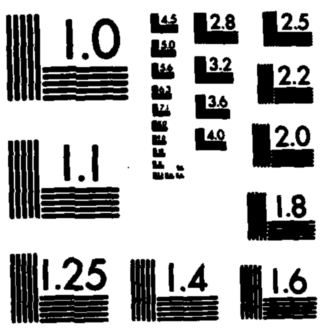
AD-A146 208 FLUID DYNAMICAL PANEL SYMPOSIUM ON WIND TUNNELS AND TESTING TECHNIQUES(U) ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT NEUILLY.. A ELSENAAR MAY 84 1/1

UNCLASSIFIED AGARD-AR-193 F/G 20/4 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART

2

AGARD-AR-193

AGARD-AR-193

AD-A146 208

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARD ADVISORY REPORT No.193

Technical Evaluation Report on the Fluid Dynamics Panel Symposium on Wind Tunnels and Testing Techniques

NORTH ATLANTIC TREATY ORGANIZATION

DISTRIBUTION AND AVAILABILITY ON BACK COVER

AGARD-AR-193

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.193

TECHNICAL EVALUATION REPORT

on the

FLUID DYNAMICS PANEL SYMPOSIUM

on

WIND TUNNELS AND TESTING TECHNIQUES

by

A.Elsenaar
NLR
P.O. Box 90502
1006 BM Amsterdam
Netherlands

The Proceedings of the AGARD Fluid Dynamics Panel Symposium Wind Tunnels and Testing Techniques which was held in Cesme, Turkey on 26–29 September 1983, are published as AGARD CP 348.

THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

The content of this publication has been reproduced
directly from material supplied by AGARD or the author.

Published May 1984

ISBN 92-835-1473-4

SPS

Printed by Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ

CONTENTS

TECHNICAL EVALUATION REPORT ON THE SYMPOSIUM ON WIND TUNNELS AND TESTING TECHNIQUES (ÇEŞME, TURKEY, 26-29 SEPTEMBER 1983)

by

A. Elsenaar

Compressible Aerodynamics Department
National Aerospace Laboratory NLR
The Netherlands

1. INTRODUCTION

In the fall of 1983, the AGARD Fluid Dynamics Panel organized a symposium on "Wind Tunnels and Testing Techniques" in Çeşme, Turkey. The theme of the symposium was announced as follows:

"The meeting is to provide a review of new facilities and their performances and to present recent results related to their design. Results of work pertaining to wind tunnel testing (scale effects, effects of disturbances, etc.) should be reported upon, as well as those on new developments in testing techniques, instrumentation and model design and construction. Finally the increasing impact of computer development on wind tunnel testing will be addressed".

To this end the symposium was divided into three main sessions on "Facilities" (8 papers), "Fluid Motion Problems" (7 papers) and "Testing Techniques" (21 papers).

The last FDP conference that covered almost the same topics, as its title - Wind Tunnel Design and Testing Techniques - implies, was held in London in 1975 (Ref. A). Goethert noted in the technical evaluation of that conference (Ref. B) that "we stand at the threshold of great advances in technology for high-performance wind tunnels". The key words that supported his view were: cryogenic testing, flexible walls, magnetic suspension, non-intrusive (laser) measurement systems and the revolutionary pace of computer development. At that time the cryogenic concept was just about to be generally accepted (at the symposium encouraging results of the 1/3 meter Transonic (pilot-) Cryogenic Tunnel of NASA Langley were presented), new large low speed facilities were conceived or under construction (NASA Ames 80x120 ft², F-1, RAE-5x5 m² and the DNW) and new approaches to old problems of wall, support and probe interference were actively pursued. Goethert also noted that these high technology windtunnels would not replace but rather supplement the existing conventional facilities. He expressed some concern with respect to the operational costs of the cryogenic facilities and pleaded for systematic studies to determine the type of problems that would justify such high costs for experimental information, studies to increase the tunnel productivity and a continuous effort to refine measuring techniques even for conventional windtunnels.

Goethert's 8 year old comments are still inspiring today. Although significant advances were reported at the present symposium, some of his recommendations have not resulted in a noticeable impact, at least at this conference. The present symposium was dominated by cryogenic testing on the one hand and refinements of conventional techniques on the other hand. Basically new approaches were hardly heard.
One should, however, keep in mind that prior to this symposium three meetings took place that touched upon its theme:

- Aerodynamics of Power Plant Installation (1981)
- Ground/Flight Test Techniques and Correlation (1982)
- Wall Interference in Wind Tunnels (1982)

The reader is referred to the conference proceedings and technical evaluation reports for further information (Ref. C to H). For a proper judgement of the progress made since the 1975 London meeting, the work reported there (and summarized at this symposium; Ref. 6 and 9) should also be considered.

In this evaluation report the division in three main sections, as mentioned in the program, is not quite followed. Instead, the various papers have been grouped around 4 themes, (see table of contents) for personal preference. Other combinations, however, could also have been made.

2. THE DAWN OF CRYOGENIC TESTING

2.1 Continuous cryogenic facilities

Although large cryogenic facilities have been extensively discussed at the 1975 London Conference, the actual construction has required so much time that none of the large facilities is fully operational at present. Construction of the 2.5x2.5 m² National Transonic Facility has been finished (Ref. 1), 8 years after the go-ahead decision. The only major design change concerns the model access system. With this system model changes can be made under "shirt sleeve conditions" by inserting access housings from both sides of the test section. Gate valves up- and downstream are used to isolate the plenum/test section region from the pressurized circuit.

At the time of this conference, NTF has made 180 hours wind-on for a major check-out. The design objectives have been met, apart from some shortfall in maximum Mach number. A maximum Reynolds number of 120×10^6 (based on 25 cm chord) was realized. Of this total running time, 130 hours were devoted to cryogenic testing, mainly spent on cooling-down and warming-up. With a rate of change of temperature of .75 K/minute, a maximum temperature jump across the outside structure of 25 °C could be maintained. This leads to a total time of 9 hours for one complete temperature cycle. After this initial "shake-down" test period the NTF is being prepared for its calibration phase. Path-finder models have been defined for comparison with the ARC 11 foot wind tunnel. Additional tunnel and flight comparisons will be made on the Boeing 767 and the Shuttle Orbiter configurations and results should be available at the end of 1984.

The European counterpart of NTF, the 2x2.4 m² European Transonic Windtunnel (ETW), is still in its design phase (Ref. 2). ETW design deviates on three main points from NTF: maximum stagnation pressure will be limited to 4.5 instead of 9 bar; external rather then internal insulation will be applied; the model access procedures will be different in the sense that in ETW the model (with support) will be removed from the test section for model changes necessitating a complete depressurization of the circuit. It is expected that 70 % of the tests will be made at cryogenic conditions.

A 1:8.8 scale model of ETW (ambient temperature) has been extensively tested to optimize the aerodynamic circuit. A cryogenic pilot facility of identical scale (the PETW) has been installed at NLR, Amsterdam and will be used for the evaluation of aerodynamic performance and cryogenic operation. The preliminary design phase is expected to finish March 1984 and the final design should be ready within two years. A suitable site for this tunnel, however, still has to be selected.

Wagner (Dornier) reported two studies related to ETW design. The theoretical study of Reynolds number effects on diffusor performance indicated that these effects can be neglected (Ref. 7). In the second, combined theoretical and experimental, study (Ref. 13), it could be established that, for typical transonic flows, supercooling of about 18 K below the static liquefaction boundary does not introduce significant condensation effects around the model, while increasing the Reynolds number by as much as 40 %.

Another large cryogenic facility, the Kryo-Kanal Köln witn a 2.4x2.4 m^2 test section, is nearing completion of construction. This tunnel is a modification of an existing low speed windtunnel, by adding 35 cm thick internal insulation. This tunnel can not be pressurized, so a maximum Reynolds number of 8.9×10^6 (based on 24 cm chord) at a maximum Mach number of 0.38 can be realized. The model access procedure will be similar to ETW. For cryogenic conditions a warming-up and cooling-down time of 4 hours (in the lock) is anticipated. With an additional model conditioning room this time can be cut down to roughly 20 minutes for minor model changes. The primary aim of this tunnel is the support of the national cryogenic technology program, but the tunnel will also provide a low cost testing capability in the low Mach number range for ETW models.

2.2 Intermittent cryogenic facilities

The increasing interest in intermittent cryogenic facilities stems from the fact that, as far as construction is concerned, a conventional (possibly already existing) tunnel can easily be converted into a cryogenic high Reynolds number facility. The Institut Aérotechnique de Saint-Cyr (Ref. 5) reported very detailed studies to "cryogenize" an Eiffel tunnel. After a pre-cooling time of 500 sec and a transition period of only 5 sec., constant cryogenic conditions are possible for 15 sec. at a Mach number close to 1. Very detailed theoretical and experimental studies were made to establish the most effective way of LN_2 injection into the air stream. Injection at two subsequent planes with whirl jet nozzles appeared to give the best results with a complete evaporation within a distance of less than 0.5 meter. Cold spots, originating from LN_2 droplets, must be avoided since they persist over a much longer length.

Similar cycle times are reported for the pressurized 0.4x0.4 m^2 induction driven cryogenic tunnel T2 of ONERA (Ref. 3): cooling down, transition and constant flow typically last 45, 10 and 25 sec. respectively. This tunnel is operational since 1975 and was modified for cryogenic testing in 1980. Outside the thermal boundary layer of roughly 5 cm thickness, the temperature is constant to within $\pm$ 1 K and the Mach number to within .002. Temperature fluctuations are less than 0.14 K RMS at 100 K (however only measured for frequencies below 50 Hz!) and pressure fluctuations are of the order of boundary layer noise. LN_2 condensation does not appear to be a problem for temperatures in excess of 100 K.
Temperature equilibrium, which is a serious problem for the intermittent cryogenic facilities, is realized in T2 by inserting the pre-cooled model only just before constant flow conditions are reached. The combination of this tunnel with flexible walls (to eliminate wall interference as already demonstrated for ambient temperature conditions) makes this tunnel a very attractive tool for 2-D Reynolds number studies up to 30 million based on model chord.

2.3 Model design

Is it, from the model design point of view, feasible to take full advantage of the increased simulation capabilities of large cryogenic facilities? This question was raised by Griffin (General Dynamics; Ref. 25) in relation to NTF. Very detailed design studies have been made for two typical fighter model configurations, a cranked wing (CWC) and the variable sweep F-111 TACT airplane. These configurations were selected for comparison with other windtunnel and flight data. Both models use a non-heated balance and a heated instrumentation bay in the nose section. The wing is constructed by molding glass-epoxy over a steel spar. A surface roughness of 20 micro inches was considered acceptable for these models although the resulting cut-off Reynolds number is lower than the maximum test Reynolds number. Some problem areas like wing joints (a mismatch of 0.002 inch under load was found in a particular test) and instrumentation cable effects on balance readings (up to 0.25 % maximum balance load in axial direction) were identified but it is expected that they can be solved. Model costs are estimated to be roughly 2 times as high as for conventional windtunnel models; a reduction in costs is expected with increased R&D.

2.4 Aerodynamic aspects

Sofar, the cryogenic facilities have been discussed rather than the aerodynamic data obtained in a cryogenic environment. Since the larger cryogenic facilities are not operational yet, more insight can only be obtained from results of a number of smaller facilities devoted to 2-D testing.

Fancher (Douglas Aircraft Co; Ref. 14) reported systematic measurements in a 1x1 ft^2 cryogenic blowdown facility on the effects of temperature non-equilibrium. It was pointed out that boundary layer transition is strongly affected by heat transfer on the model surface: at zero pressure gradient, a 1 % deviation from the adiabatic wall temperature may cause a 7 % variation in transition Reynolds number. It is also well-known that surface roughness effects (the very smooth surface as required at the highest Reynolds numbers is difficult to realize; Ref. 25) and flow unsteadiness (possibly introduced by LN_2 injection; see Section 3.2) will affect the transition process. For these reasons a correct simulation of the transition location might represent a major problem for high Reynolds number testing unless the transition point location is dominated by the pressure gradient. It was also shown, both theoretically and experimentally, that the length scale for shock-wave/boundary layer interaction is strongly affected by temperature non-equilibrium. In general, flows with separation seem to be critical in this respect. Overall changes in lift and drag, however, are not alarming, though not quite insignificant. Fancher's observations roughly agree with those made in T2 (Ref. 3) where it was found that a 1 % deviation from the adiabatic wall temperature corresponds to a 3 % Reynolds number variation (for a fixed transition point location). Very rightly, the point was made that, for an adequate simulation in the windtunnel, possible temperature non-equilibrium effects in flight must also be known.

In a joint NASA/DFVLR investigation (Stanewsky et al; Ref. 10) two airfoil models of different chord lengths but of the same profile, were tested in the 0.3x0.3 m^2 pilot cryogenic tunnel of NASA (the TCT). The results could be compared with results obtained in conventional, pressurized high Reynolds number facilities (notably Lockheed's CFWT and DFVLR's TWB and TKG). The lack of agreement is rather disappointing but, although the analysis is still going on, there are no indications of typical cryogenic measuring problems. Wall interference effects seem to be the main cause for the observed discrepancies. Important side wall effects are believed to be present for model aspect ratios smaller then 2 whereas in the tests the aspect ratio varied between 1.33 and 5. Interference effects of top and bottom walls are largely unknown. Discrepancies between drag-rise Mach numbers of up to 0.020 clearly indicate that the effective free-stream Mach number is not properly established. As a result very inconsistent trends with Reynolds number in drag-divergence and maximum lift are found. However, some consistency is observed when maximum lift is plotted as a function of Reynolds number at the drag-rise Mach number as measured in a particular test (tunnel/ model combination). The paper illustrates, rather dramatically, that Reynolds number effects are easily mixed up with measuring uncertainties like unknown wall interference effects, a statement that was also made in reference 6. It also implies that, in order to take full advantage of the cryogenic windtunnels, more advanced wall correction methods should be implemented as well. The T2 facility (Ref. 3) of ONERA, that combines cryogenic technology with flexible walls is very promising in this respect.

3. WALL INTERFERENCE AND FLOW QUALITY: A STEP AHEAD

3.1 Wall interference

The review paper (Ref. 6) of the FDP meeting on "Wall Interference in Wind Tunnels" (London, May 1982; Ref. G and H) by Kraft and Binion reflected some optimism with respect to the assessment of wall interference. It is now almost generally accepted that the classical homogeneous boundary condition at the tunnel walls should be replaced by an "in-situ" measured boundary condition in terms of pressure and flow direction. It can then be shown that the complete wall interference flow field can be calculated without knowledge of the model. These methods have almost reached a mature state for two dimensional testing and extensions to three-dimensional flows are on their way. Routine measurement of the flow direction near ventilated walls still is an important practical problem. For solid test section walls this problem is absent of course. In that case global Mach number and angle of incidence corrections can be determined accurately. The remaining wall effects can then be expressed in terms of flow non-uniformity over the airfoil chord or model. It was shown that these effects can be adequately removed with adaptive walls although much work still has to be done for three dimensional flows. Nevertheless, the principles of both techniques (preferably used in combination) have proven to be sound. But it is also clear that not all problems have been solved. Wall interference for conditions with shock reflections from the walls is such an unsolved problem. Tunnel side wall effects are only poorly understood. And the application of measured boundary condition methods or flexible walls for three-dimensional flows on a routine basis is still a difficult measuring and engineering problem that will be of considerably influence on the day-to-day tunnel operation.

There still is a noticeable interest in the behaviour of conventional slotted or perforated walls. The London meeting showed some typical examples. In the present conference Firmin (RAE; Ref. 8) reported on detailed flow measurements near a slotted wall. He showed clear evidence of a large inflow from the plenum chamber into the test section accompanied by highly three-dimensional separation patterns. This might have consequences for the application of measured boundary condition wall interference correction methods (as discussed above) when low energy plenum air is entering the domain of the computational region. As a "rule of the thumb" it can be stated that homogeneous flow is reached at about one slot-spacing away from the wall.

Dynamic measurements in solid wall windtunnels might suffer from tunnel resonance effects. In a purely theoretical contribution from Mokry (NRC/NAE; Ref. 15), the acoustic impedance concept has been applied to ventilated walls to calculate resonance frequencies. If this will be actually measured in ventilated test sections remains to be seen in view of the assumed homogeneous boundary condition (note that wall interference theory moves away from this approach at present) and the occurrence of viscous damping and refraction effects.

3.2 Flow quality

Almost next to Reynolds number effects and tunnel wall interference, the question of the required flow quality is of much concern. Clearly, the answer to this question depends on the application one has in mind. There is ample evidence that wall induced pressure fluctuations have large effects on the natural transition point location. It is even more important to note that the required velocity fluctuation level for meaningful laminar flow testing is a strong function of Reynolds number (see Fig. 6 of Ref. 12). This was one of the incentives for NASA to start a systematic investigation of flow quality and ways to improve existing NASA windtunnels. The results of this investigation were reported by Owen et al (Ref. 12). Pressure and velocity fluctuation levels have been established for a number of wind tunnels and some examples were given on how the flow quality can be improved by conventional means like screens, suppression of large scale separations in the circuit and a second throat.

Michel (DFVLR; Ref. 11) dealt with flow quality in a more fundamental way. Of the three basic fluctuation modes of vorticity, entropy and pressure, only the last one was discussed in some detail. For free-jet facilities a lower limit of C_p-RMS = 0.002 was derived on the assumption that all noise is generated by the free shear layers. It was shown that the DNW (Ref. 18) has actually reached this limiting value. For a solid wall test section a lower limit is expected, determined by noise radiated from the wall boundary layers. Values of 0.0015 to 0.0006 (in axial velocity fluctuation level and depending on Reynolds number) were derived as compared with .002 for free-jet facilities.

Both papers on flow quality expressed their concern with respect to the fluctuation level in cryogenic facilities due to LN_2 injection. As pointed out by Michel, not only the temperature fluctuations themselves, but also a possible detrimental effect on the vorticity fluctuation level (due to the coupling of the two modes in the contracted nozzle flow) are the basis of this concern. Unfortunately, no results were reported at the conference to appease this concern. The fluctuation measurements at cryogenic conditions in T2 (Ref. 3) were limited to relatively low frequencies, yielding "eddy" sizes of the order of the test section dimensions or even larger. Measurements in the TCT (Ref. 12) have not yet been extended to cryogenic conditions; moreover, the reported velocity fluctuation level at ambient temperature condition is already alarmingly high. These measurements are very difficult to make but there is no doubt that they should be done to increase the understanding of cryogenic flow quality. The problem certainly deserves much more attention.

4. SPECIAL TESTING TECHNIQUES: WIDER AND BETTER SIMULATION

4.1 Acoustic measurements

At the conference some examples were shown of acoustic measurements in windtunnels with test section dimensions as small as .3x.3 m^2 (at Ankara; Ref. 19) up to the 6x8 m^2 (DNW; Ref. 18). Additionally in flight acoustic measurements were reported.

Small scale facilities can be successfully used for basic acoustic research. At the Middle East Technical University in Ankara (Ref. 19) near wake hot-wire and far field noise measurements were made behind a cylinder in cross-flow. By changing Reynolds number and/or surface roughness the sub-, trans- and supercritical flow regimes could be established. In the 3x3 m^2 low speed windtunnel of DFVLR in Göttingen noise generation of advanced propellors has been studied (Ref. 18).

The same paper showed two comparisons between windtunnel and flight noise measurements. One was related to noise spectra on the cabin wall below a helicopter rotor. The comparison was good for hover conditions but less satisfactory for forward flight. For these conditions the windtunnel (this time an industrial upon jet facility) data showed higher energy content for the higher harmonics.

The second comparison with flight test results (on helicopter far field noise), was obtained from acoustics tests in the 8x6 m^2 DNW. This tunnel can be operated in an open jet mode for acoustic measurements. In the paper by Michel (Ref. 11) it was already indicated that the turbulence level in this tunnel is close to the theoretical minimum for an open jet facility. The acoustically treated testhall walls eliminate virtually all reflections. The agreement with flight tests for high speed impulsive noise ("blade slap") was very convincing, both in pressure pulse shape and overall noise levels. This tunnel appears to be a very useful tool for acoustic measurements in view of its good flow characteristics and its large test section dimensions, enabling in- and out-of-flow acoustic measurements.

4.2 Dynamic measurements

There were 5 contributions in the field of dynamic measurements. Gravelle (ONERA; Ref. 34) presented some typical applications of unsteady measurements on 2-D airfoils and half-models with forced oscillations of the wing and/or of control surfaces, the latter in relation to the development of active control systems. Half-models are particularly suitable for tests where sizeable actuators and a very large number of pressure transducers must be accomodated. An example was shown of a half-model wing equipped with 400 kulites and 500 conventional pressure tappings.

Welsh (RAE; Ref. 36) described a technique based on semi-conductor pressure transducers for the simultaneous measurement of steady and unsteady pressures, using a sophisticated temperature compensation circuit. This, combined with a fast frequency sweep excitation, makes it possible to obtain detailed steady and unsteady measurements in a single run. Accurate steady results could be obtained in this way, but the non-steady part showed some frequency dependent differences as compared with the more conventional discrete excitation technique. Tunnel unsteadiness, propagating upstream from the diffusor, is believed to be the origin of these differences.

Ritchie (Ref. 35) presented a kind of progress report on current work on dynamic inlet distortion for fighter-type air intakes.

Hanff (Ref. 17) reported some new developments at the Unsteady Aerodynamics Laboratory of NAE concerning dynamic testing of three dimensional models. A pitch & yaw and a translation type apparatus were re-designed for higher loads. Also, an increased demand for large amplitude oscillations was noted. Since at these large amplitudes the aerodynamic reactions are no longer linearly related to the primary motion, more advanced data-reduction techniques, based on Fast Fourier Transforms, must be used. Reducing testing times is another demand. The so called "orbital apparatus", as shown at the conference, makes it possible in principle, to derive a complete set of dynamic derivatives from a sequence of three tests instead of the usual practice of 5 tests on 3 different apparatuses. The effect of sting oscillations on the measurements does present a problem, but corrections seem to be possible. It is nevertheless good practice to reduce the sting motions as much as possible.

The problem of sting interference was also addressed by Ericcson (Lockheed Missiles & Space Co.; Ref. 16) and some dramatic examples were shown. The main part of this paper, however, concentrated on the Reynolds number problem for dynamic tests. The strong coupling between the instationary flow field and the transition point location presents a very severe problem for low Reynolds number tests, especially when flow separations are present. A possible correction procedure was outlined. In this approach steady high Reynolds number data are coupled with unsteady sub-scale measurements using an approximate mathematical model. The approach is based on the assumption that the relation between steady and unsteady results is not affected by Reynolds number. Unfortunately, this is not always the case, especially for high incidence slender forebodies where the body motion itself is extremely important to the separation position. It is questionable if large cryogenic facilities are of much help here in view of the sensitivity of boundary layer transition to surface roughness and heat transfer effects (Ref. 14).

4.3 Engine simulation

A number of papers dealing with various aspects of engine simulation, underlined the ever increasing need for detailed measurements in this field.

Reference 26 by Bertolone from Aeritalia showed a rather conventional but still very useful approach to study afterbody effects on a fighter configuration. Compressed air for jet simulation was ducted through the wing-tips (mounted on a twin-sting arrangement). The afterbody forces could be measured separately by an internal balance. A great number of pressure taps was installed to study the influence of tail-fins, control deflections and secondary jets in detail. Care had to be taken to reduce and correct for sealing effects between model and afterbody.

This test set-up was evaluated in more detail by Price and Peters (Calspan; Ref. 24). They investigated various model support systems: twin-sting support (similar to the one of Ref. 26), a rear sting with an annular jet around it and a single strut attached to the forward part of the body. Dummy stings and support parts were used to localize the most important sources of interference. Axial forces were derived from pressure integration only. The conclusion was that the rear sting with an annular jet (for sting / jet diameter ratio's as large as .865) yielded the best results in an absolute sense. However, all support systems gave acceptable results (except for near-sonic conditions) when measurements were taken relative to a base-line nozzle configuration. In the same paper limitations of and possible corrections for cold jet simulation were discussed both for jet interference effects and thrust reverser tests.

Sofar the studies were related to jet effects on the external flow. Optimization of under-wing mounted engines for transport-type configurations requires a simulation of inlet and outlet flow conditions. This can be done, at least approximately, with turbine powered simulators (TPS). No papers were presented on this topic, but the technique was amply discussed at the latest AGARD conference on "Aerodynamics of Power Plant Installation". (Toulouse, May 1981, Ref. C). The growing interest in this technique, however, was indicated by two papers (Refs. 28, 29) describing new designs of TPS calibration facilities. In both facilities a pressure vessel is used to enforce the necessary static pressure ratio over the engine. The facilities differ, however, in the way the forces are measured. At DFVLR (Ref. 28) the TPS-engine is mounted directly on the balance. At ONERA (Ref. 29) the engine plus the pressure vessel is mounted on a (halfmodel) balance which is also used for the eventual wind-tunnel tests. In this set-up the engine exhausts into a second larger vessel. In a smaller facility, for 0.1 m diameter engines, this second vessel is connected to a vacuum tank for pressure control. In a larger facility, for 0.23 m diameter engines, the ejector effect of the TPS-engine itself is used to obtain sub-atmospheric conditions.

Afterbody tests and TPS-measurements are both examples of aircraft performance oriented studies. A second equally important aspect concerns the functioning of the engine itself in relation to the inlet flow conditions. This requires tests on the full scale engine with simulated inlet flow conditions including uniform and distorted steady flows and distorted unsteady flows. Such test facilities were discussed by Mitchell (AEDC) in his review paper (Ref. 21). He pointed out that direct-connect engine test facilities have serious limitations with respect to dynamic interference effects between inlet and engine. One step further is the simulation of part of the airframe and external inlet contour as well. The extensively used free jet facility of RAE at Pyestock is at present one of the best examples. A similar, but larger set-up, the Aeropropulsion Systems Test Facility is presently under construction at AEDC and will be ready at the end of 1985. The ultimate goal is a facility with independently controlled inlet and outlet flow conditions to simulate the complete range of flight conditions.

4.4 Store separation

The conference showed three contributions related to the experimental determination of store trajectories. ARA (Ref. 30) has a two-sting, six degree of freedom rig for captive trajectory testing operational since 1979. The present paper was mainly concerned with further improvements of this system. Basic short-comings of this set-up, like ejector release, dynamic effects on incidence and Mach number, thrust representation, can partly be accounted for in the calculation scheme. The most important constraint is the mechanical limitation of the system. Besides efforts to improve this, further activities concentrate on blown (parent) models, over-wing release and pressure probe grid surveys. Fluidyne (Ref. 31) has recently finished the construction of a similar apparatus for use in a $1.2 \times 1.2\ m^2$ blow down windtunnel and some first results were presented.

A much more dynamic simulation is obtained with the Light Model Technique. However, due to the model scaling the ratio between aerodynamic and gravitational forces is not correct and separation distances are consequently not well represented. The simulation can be improved with the so-called accelerated Light Model Technique (British Aerospace; Ref. 32) in which the acceleration deficit is compensated by moving the parent model in upward direction with an acceleration roughly equal to the model scale times g. Dynamic incidence effects can partly be compensated for by pitching the parent model simultaneously or (for ejector release) providing the store with an initial pitching moment. Computer simulation has indicated that this combination gives satisfactory results in most cases. The technique is especially attractive for small windtunnels where other methods fail.

4.5 Half-model testing

A large number of wind-tunnel tests is made on half-models: Reynolds number studies, flutter tests (see Ref. 20, 34) and engine simulation (Ref. 29). Elsenaar (NLR; Ref. 23) reported a systematic investigation to assess the half-model test technique. In this investigation the results of 5 different half-model configurations were compared with the corresponding results of full-model tests at the same Reynolds number. Fuselage-only measurements were included in this comparison. It was concluded that next to side-wall mounting effects, the very substantial wall interference effects are a primary cause of discrepancies for large half-models. In the absence of reliable three-dimensional wall interference correction methods, these effects can at present only be determined empirically from a comparison with the corresponding full-model tests. In fact, this is another way of saying that half-model tests should not be trusted for their absolute accuracy, but are still very useful for relative tests.

4.6 Flow field measurements

Two contributions were concerned with flow field surveys. ONERA (Ref. 33) constructed a universal, computer controlled probe traversing mechanism for use in their large facilities (F1 and S1-MA). The interest is towards flow-field surveys above delta wings or behind slender bodies at high incidences. Rakes, five-hole probes and hot-wire sensors can be installed. Comparisons between the various techniques were shown. As a particularly nice example of computer controlled probe positioning, it was demonstrated that a streamline above a delta wing could actually be followed by the probe.

It is interesting that this example illustrates the refined use of conventional techniques rather then resorting to a laser velocimetry system, although work at ONERA is also along this line.

In a contribution by Walker (AEDC; Ref. 27) laser measurements behind nozzle afterbodies were discussed. In this particularly difficult flow (large velocity gradients and separated flow) problems were encountered with respect to particle lag (for which a correction,in some cases as large as 10 %, was derived) and non-homogeneous particle distributions (giving rise to large measurement uncertainties). Examples were shown where seeding affected the flow field. Nevertheless, in such a case conventional techniques would be even more difficult to use.

5. AERODYNAMIC DESIGN: FROM WINDTUNNEL TO FLIGHT

In view of the sometimes very specialized and detailed contributions on windtunnels and testing techniques, one almost forgets the final aim of windtunnel testing: to assist the aerodynamic design of aircraft. Two contributions, one related to the beginning and the other to the very end of the design process, were of some help to take us back to this reality. Marazzi (Aeronautica Macchi; Ref. 20) reported on the use of small scale facilities in the preliminary design phase. Even tests in a very modest windtunnel, in this case a 2 m diameter open jet facility,can be very useful for configuration studies. This is especially true when used in combination with sophisticated equipment for rapidly obtaining detailed information. This point was illustrated with results of a rotary balance to study spin characteristics and half-model flutter tests on wing/store combinations.

The other end of the spectrum was covered by a paper of Saiz and Quemard (Aerospatiale/ONERA; Ref. 22) presenting a windtunnel/flight comparison for the Airbus A-310 in the low speed regime. In this particular case the wind-tunnel tests were made in one of the more sophisticated European low-speed windtunnels, the $3.5 \times 4.5\ m^2$, pressurized (4 bars) windtunnel F-1 of ONERA. The A-310 aircraft was represented in great detail (scale 1:14). Much effort was spent in the determination of support corrections, both experimentally and theoretically. The final comparison with flight data turned out to be very good, in spite of Reynolds number defects and flow-through-engine simulation.

Poisson-Quinton (ONERA; Ref. 9) stressed the point that such a nice agreement between wind tunnel and flight is not always found. He showed, as a typical illustration, results of drag predictions for 12 civil transport aircrafts. In 6 cases the wind tunnel underestimated the drag (up to 22 %) whereas in 4 cases the drag was overpredicted (up to 10 %). Comparisons of pitching moments, buffet and a-symmetric derivatives told the same story. The origins of the discrepancies are not always (or generally not?) known. In fact, such a comparison is the outcome of complex manipulations (most often unknown to other parties) based on various wind-tunnel tests, theoretical models, flight data reduction and engineering experience. These items are rarely disclosed in a systematic and coherent way.

The larger part of the review paper by Poisson-Quinton was devoted to the outcome of the AGARD conference on "Ground/Flight Test Techniques and Correlation" (Toulouse 1982; Ref. E). Since some of the conclusions of that conference are equally applicable to the present meeting, they will be discussed in the final section of this evaluation report.

6. DISCUSSION AND RECOMMENDATIONS

Of the five key-words for high performance windtunnels that Goethert mentioned in his technical evaluation report of the 1975 London meeting on "Wind Tunnel Design and Testing Techniques", only cryogenic testing received considerable attention at the present conference. And even for cryogenic testing, we are awaiting the first aerodynamic data from large facilities. Goethert extensively discussed operational aspects of cryogenic testing and he noted a shift from initial investment to operational costs. The considerable cooling-down and warming-up times will affect the productivity of these new wind tunnels. It is interesting to note in this context that the already built or planned large facilities show some essential differences in model handling and thermal insulation. One might wonder what consequences this will have for the day-to-day operation.

Although cryogenic testing seems to be the only acceptable answer to high Reynolds number testing, some new problems are intrinsically connected with this technique. Typical cryogenic aspects, like the effects of temperature fluctuations and temperature non-equilibrium should be studied in greater depth in the existing small scale cryogenic facilities. These problems will add to the already existing uncertainties in wind tunnel testing.

Although not reported in detail at this conference, quite significant progress has been made in the field of wall interference. This applies to both passive (assessment of wall interference) and active (elimination of wall interference) walls. The conference also showed quite convincingly that these advancements should be integrated with cryogenic testing. Otherwise, no progress will be made in the understanding of Reynolds number effects or, even worse, we will be heading for more confusion.

Conventional wind tunnels are still in business and will be so in the future. It is therefore very reassuring that a large number of papers was devoted to a critical evaluation of existing and sometimes rather conventional test techniques. A better understanding of the things we are actually measuring is a first step to improvements upon existing techniques. In fact, the conference showed quite a few improvements of existing techniques that significantly increased the simulation capabilities. This is particularly true for difficult fields like engine simulation, store separation and dynamic tests.

In contrast to this, the absence of significant contributions in the other key-areas as mentioned by Goethert in 1975 should be noted. Magnetic suspension was not discussed at all. Laser measurements were deliberately excluded by the program committee*. The role of computers in wind tunnel testing was not addressed specifically. But there is no doubt that computers rapidly advance in wind tunnel test techniques. Flexible walls, captive trajectory testing, probe positioning are all computer controlled. Wall and support interference assessment relies on fluid dynamic calculations. But the use of computers to "provide a clever and quick synthetic presentation of millions of data points" (Poisson Quinton, Ref. 9) was not discussed at all. In the same review paper the fear was expressed that "engineers may loose track of the physics of the process of prediction and comparisons". It is in this area where the role of the computer will become essential in the future: to simulate and clarify the basic process from wind tunnel to flight, step-by-step, in a consistent and logical order.

The conference showed two convincing examples of wind tunnel flight comparison: one related to far field helicopter noise, the other concerned with low-speed characteristics of the Airbus A-310. It is not by chance that both comparisons were based on results obtained in new large scale wind tunnels that are typical for a new generation of test facilities. From that point of view the future looks very bright, especially when large cryogenic facilities will be operational. But we cannot expect simulation to be perfect in all cases or in every respect, even when Reynolds number is duplicated or wall interference well defined. It will be increasingly difficult to trace the origins of possible discrepancies between theory, wind tunnel and flight. There might be simulation problems, at present only partly understood or a mis-understanding between the involved diciplines. In that situation a further advancement is only possible when specialists of the respective fields are made more aware of the procedures, lines of thinking and problem areas in their neighbouring fields.

This requires, on a small scale, an integration of test-engineers, windtunnel-engineers, wall interference specialists and theoretical aerodynamicists. On a larger scale an integration of the main diciplines from CFD to Flight Tests with the Wind Tunnel somewhere in the middle, is needed. This observation is not a new one and can be found in many technical evaluation reports. AGARD at present is organized along the lines of these broad diciplines. Within each dicipline specialists' meetings play a key role in the transfer of information. Therefore the question should be raised if new and un-conventional ways of organizing specialists should be tried within AGARD to stimulate this process of integration.

References

I AGARD publications of related conferences

A - Wind Tunnel Design and Testing Techniques. AGARD-CP-174 (October 1975)
B - Goethert, B.H. Technical Evaluation Report (of Ref. A). AGARD-AR-97 (August 1976)
C - Aerodynamics of Power Plant Installation AGARD-CP-301 (May 1981)
D - Henderson, W.P. Technical Evaluation Report (of Ref. C) AGARD-AR-173 (June 1982)
E - Ground/Flight Test Techniques and Correlation AGARD-CP-339 (October 1982)
F - Williams, J. Technical Evaluation Report (of Ref. E)AGARD-AR-191 (June 1983)
G - Wall Interference in Wind Tunnels AGARD-CP-335 (May 1982)
H - Binion, T.W. Jr. Technical Evaluation Report (of Ref. G) AGARD-AR-190 (March 1983)

II Symposium Contributions

1. Operational Experience with the National Transonic Facility, L.W. McKinney, NASA Langley, USA
2. Status Report on the European Transonic Windtunnel ETW, R.J. North, J.P. Morel, J. Prieur, J.A. Tizard, Technical Group ETW, NE, FR
3. The Self-correcting Cryogenic Windtunnel T2 at ONERA/CERT, A. Mignosi, J.B. Dor, ONERA/CERT, FR
4. The Cryogenic Wind Tunnel; Cologne, G. Viehweger, DFVLR, GE
5. Production of a Cryogenic Blow in an Eiffel-type Wind Tunnel, D. Chauvet, Institut Aérotechnique de Saint-Cyr; Ch. Dujarric, STPA, FR
6. Conclusions and an Update from the FDP Specialists' Meeting (London) on Wall Interference in Wind Tunnels (Invited), T.W. Binion Jr., AEDC, TN, USA
7. Turbulent Diffusor Flow Studies Related to the Design of the ETW-Diffusor, H.-W. Stock, Dornier GmbH, GE
8. Disturbances from Ventilated Tunnel Walls in Aerofoil Testing, M.C.P. Firmin, P.H. Cook, RAE Farnborough, Hants, UK
9. Ground/Flight Test Techniques and Correlation (Invited), Ph. Poisson-Quinton, ONERA, FR
10. Tests with the Transonic Airfoil CAST 10-2/DOA2 at High Reynolds Numbers under Ambient and Cryogenic Temperature Conditions, E. Stanewsky, F. Demurie, DFVLR-AVA, GE; E.J. Ray, C.B. Johnson, NASA Langley, USA
11. Definition, Sources, and Lowest Possible Levels of Wind-Tunnel Turbulence, U. Michel, E. Froebel, DFVLR-Berlin, GE
12. A Program for the Evaluation and Improvement of Flow Quality in NASA Wind Tunnels, F.K. Owen; Complere Inc.; P.C. Stainback, W.D. Harvey, NASA Ames, USA
13. Prediction of Condensation Onset and Growth in the European Transonic Windtunnel ETW, B. Wagner, Dornier, and M. Duker, DFVLR, GE
14. Nonadiabatic Model Wall Effects on Transonic Airfoil Performance in a Cryogenic Wind Tunnel, F.T. Lynch, M.F. Fancher, Douglas Aircraft Co.; G.R. Inger, U of Colo, USA
15. Prediction of Resonance Frequencies for Ventilated Wall Wind Tunnels, M. Mokry, NRC/NAE, Ottawa, CA
16. Practical Solutions to Simulation Difficulties in Subcale Wind Tunnel Tests, L.E. Ericcson, J.P. Reading, Lockheed Missiles & Space Co., USA
17. Recent Developments and Future Directions in Dynamic Stability Research at NAE, K.J. Orlik-Ruckemann, E.S. Hanff, M.E. Beyers, NRC/NAE, Ottawa, CA
18. Propeller and Rotor Noise Testing in Low Noise Wind Tunnels, H. Heller, W. Splettstoesser, R. Neubauer, and F. Grosche, DFVLR, GE
19. Aeroacoustic Noise Measurements in Wind Tunnel, N. Alemdaroglu, Middle East Technical University, Ankara, TU

* Only paper 27 was added at a later date to replace a withdrawn contribution

20. The Use of Small Scale Wind Tunnel and Model Shop at Aeronautica Macchi as an Industrial Tool
    S. Comoretto, D. Malara, R. Marazzi, F. Facori, Aeronautica Macch, IT
21. Fluid Dynamic Aspects of Turbine Engine Testing (Invited), J.G. Mitchell, AEDC, TN, USA
22. ONERA F1 Wind Tunnel Test/Wind Tunnel-Flight Comparisons, C. Quemard, ONERA, M. Saiz, Aerospatiale, FR
23. Half-model Testing in the NLR High Speed Wind Tunnel HST: Its Technique and Application, S.J. Boersen, A. Elsenaar, NLR, Amsterdam, NE
24. Test Techniques for Jet Effects on Fighter Aircraft, E.A. Price Jr., W.L. Peters, Calspan Field Services, AEDC, TN, USA
25. Design of Advanced Technology Maneuvering Aircraft Models for the National Transonic Facility, S.A. Griffin, General Dynamics Convair, San Diego, USA
26. Design of a Wind Tunnel Afterbody Model For the Development of a Transonic Combat Aircraft, G. Bertolone, E. Farinazzo, Aeritalia Torino, IT
27. Transonic Nozzle-Afterbody Flow Field Measurements using a Laser Doppler Velocimeter, F.H. Heltsley, B.J. Walker, R.H. Nichols, AEDC, USA
28. The New Calibration Tank for Engine Simulators in DFVLR Göttingen, B. Binder, E. Melzer, R. Wulf, DFVLR, Göttingen, GE
29. New TPS Calibration Bench, J.P. Becle, J. Coste, J. Leynaert, ONERA, FR
30. Recent Developments in store Separation and Grid Survey Techniques Using the ARA Two-sting Rig, M.E. Wood, ARA Ltd., Bedford, UK
31. A Selfcontained Captive Trajectory System for a Blowdown Wind Tunnel, C.D. Christopherson, D.N. Kamis, D.M. Nelson, F.D. Week, Fluidyne Minneapolis, USA
32. The Accelerated Light Model Technique of Store Separation Simulation as Developed and Used at British Aerospace Brough, R.E. Burns, British Aerospace, Brough, UK
33. Vortical Flow Exploration Methods Developed for the F1 Wind Tunnel, Y. Brocard, Ph. Desplas, ONERA, FR
34. New Methods of Excitation Data Acquisition and data Reduction for unsteady Wind Tunnel Tests, A. Gravelle, S. Destuynder, ONERA, FR
35. Experience in Engine Face, Non-Steady, Flow Measurements through a Side and Bottom Engine Air Inlet Duct, D. Ritchie, Dornier, Friedrichshafen, and R. Friedrichs, DFVLR, GE
36. Recent Developments in the Measurement of Time-dependent Pressures, B.L. Welsh, C.R. Payne, B.E. Cripps, RAE, Bedford, UK

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-193	ISBN 92-835-1473-4	UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title

WIND TUNNELS AND TESTING TECHNIQUES

7. Presented at

8. Author(s)/Editor(s)	9. Date
A.Elsenaar	May 1984

10. Author's/Editor's Address		11. Pages
	NLR P.O. Box 90502 1006 BM Amsterdam Netherlands	14

12. Distribution Statement This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors

Wind tunnels
Test equipment
Tests
Wind tunnel models
Measuring instruments

14. Abstract

The theme of the symposium was to provide a review of new facilities and their performances and to present recent results related to their design. Results of work pertaining to wind tunnel testing (scale effects, effects of disturbances, etc.) was reported upon, as well as those on new developments in testing techniques, instrumentation and model design and construction. Finally the increasing impact of computer development on wind tunnel testing was addressed.

To this end the symposium was divided into three main sessions on: "Facilities" (8 papers); "Fluid Motion Problems" (7 papers), and "Testing Techniques" (21 papers). In this evaluation report the division in three main sections, as mentioned in the program, is not quite followed. Instead, the various papers have been grouped around 4 themes, (see table of contents) for personal preference. Other combinations, however, could also have been made.

The Proceedings of the AGARD Fluid Dynamics Panel Symposium Wind Tunnels and Testing Techniques which was held in Cesme, Turkey on 26–29 September 1983, are published as AGARD CP 348. The present report summarizes and evaluates the meeting.

AGARD Advisory Report No.193	AGARD-AR-193
Advisory Group for Aerospace Research and Development, NATO WIND TUNNELS AND TESTING TECHNIQUES by A.Elsenaar Published May 1984 14 pages The theme of the symposium was to provide a review of new facilities and their performances and to present recent results related to their design. Results of work pertaining to wind tunnel testing (scale effects, effects of disturbances, etc.) was reported upon, as well as those on new developments in testing techniques, instrumentation and model design and construction. Finally the increasing impact of computer development P.T.O	Wind tunnels Test equipment Tests Wind tunnel models Measuring instruments

AGARD Advisory Report No.193	AGARD-AR-193
Advisory Group for Aerospace Research and Development, NATO WIND TUNNELS AND TESTING TECHNIQUES by A.Elsenaar Published May 1984 14 pages The theme of the symposium was to provide a review of new facilities and their performances and to present recent results related to their design. Results of work pertaining to wind tunnel testing (scale effects, effects of disturbances, etc.) was reported upon, as well as those on new developments in testing techniques, instrumentation and model design and construction. Finally the increasing impact of computer development P.T.O	Wind tunnels Test equipment Tests Wind tunnel models Measuring instruments

AGARD Advisory Report No.193	AGARD-AR-193
Advisory Group for Aerospace Research and Development, NATO WIND TUNNELS AND TESTING TECHNIQUES by A.Elsenaar Published May 1984 14 pages The theme of the symposium was to provide a review of new facilities and their performances and to present recent results related to their design. Results of work pertaining to wind tunnel testing (scale effects, effects of disturbances, etc.) was reported upon, as well as those on new developments in testing techniques, instrumentation and model design and construction. Finally the increasing impact of computer development P.T.O	Wind tunnels Test equipment Tests Wind tunnel models Measuring instruments

AGARD Advisory Report No.193	AGARD-AR-193
Advisory Group for Aerospace Research and Development, NATO WIND TUNNELS AND TESTING TECHNIQUES by A.Elsenaar Published May 1984 14 pages The theme of the symposium was to provide a review of new facilities and their performances and to present recent results related to their design. Results of work pertaining to wind tunnel testing (scale effects, effects of disturbances, etc.) was reported upon, as well as those on new developments in testing techniques, instrumentation and model design and construction. Finally the increasing impact of computer development P.T.O	Wind tunnels Test equipment Tests Wind tunnel models Measuring instruments

on wind tunnel testing was addressed.

To this end the symposium was divided into three main sessions on “Facilities” (8 papers), “Fluid Motion Problems” (7 papers) and “Testing Techniques” (21 papers). In this evaluation report the division in three main sections, as mentioned in the program, is not quite followed. Instead, the various papers have been grouped around 4 themes, (see table of contents) for personal preference. Other combinations, however, could also have been made.

The proceedings of the AGARD Fluid Dynamics Panel Symposium Wind Tunnels and Testing Techniques which was held in Cesme, Turkey on 26–29 September 1983, are published as AGARD CP 348.

ISBN 92-835-1473-4

on wind tunnel testing was addressed.

To this end the symposium was divided into three main sessions on “Facilities” (8 papers), “Fluid Motion Problems” (7 papers) and “Testing Techniques” (21 papers). In this evaluation report the division in three main sections, as mentioned in the program, is not quite followed. Instead, the various papers have been grouped around 4 themes, (see table of contents) for personal preference. Other combinations, however, could also have been made.

The proceedings of the AGARD Fluid Dynamics Panel Symposium Wind Tunnels and Testing Techniques which was held in Cesme, Turkey on 26–29 September 1983, are published as AGARD CP 348.

ISBN 92-835-1473-4

on wind tunnel testing was addressed.

To this end the symposium was divided into three main sessions on “Facilities” (8 papers), “Fluid Motion Problems” (7 papers) and “Testing Techniques” (21 papers). In this evaluation report the division in three main sections, as mentioned in the program, is not quite followed. Instead, the various papers have been grouped around 4 themes, (see table of contents) for personal preference. Other combinations, however, could also have been made.

The proceedings of the AGARD Fluid Dynamics Panel Symposium Wind Tunnels and Testing Techniques which was held in Cesme, Turkey on 26–29 September 1983, are published as AGARD CP 348.

ISBN 92-835-1473-4

on wind tunnel testing was addressed.

To this end the symposium was divided into three main sessions on “Facilities” (8 papers), “Fluid Motion Problems” (7 papers) and “Testing Techniques” (21 papers). In this evaluation report the division in three main sections, as mentioned in the program, is not quite followed. Instead, the various papers have been grouped around 4 themes, (see table of contents) for personal preference. Other combinations, however, could also have been made.

The proceedings of the AGARD Fluid Dynamics Panel Symposium Wind Tunnels and Testing Techniques which was held in Cesme, Turkey on 26–29 September 1983, are published as AGARD CP 348.

ISBN 92-835-1473-4

The Proceedings of the AGARD Fluid Dynamics Panel Symposium *Wind Tunnels and Testing Techniques* which was held in Cesme, Turkey on 26–29 September 1983, are published as AGARD CP 348.

END

FILMED

10-84

DTIC